V.—*Note on the Variation of the Barometric Tides in connection with Diurnal Land- and Sea-Breezes.*—*By* Henry F. Blanford, *Meteorological Reporter to the Government of India.*

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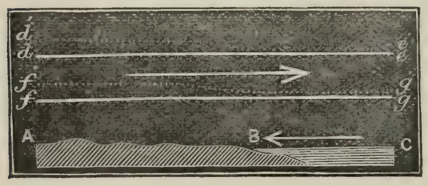
The theory of the diurnal land- and sea-breezes on sea-coasts is perhaps one of the most familiar of meteorological topics, and the subject finds a place in all our handbooks of meteorology and physical geography, as an illustration of winds of convection. It has long been surmised, as a deduction from the theory, that the daily oscillations of pressure over the sea and the land, in the neighbourhood of coast-lines, must shew marked differences; the pressure being higher over the land during the night and early morning, over the sea during the afternoon and evening hours. Hitherto, however, as far as I am aware, this inference has never been confirmed by the results of actual observation; and the following facts, relating to the diurnal variation of pressure over the head of the Bay of Bengal between 60 and 120 miles from the coast of the Súnderbans, will therefore have that interest which must always attach to the confirmation of a familiar theory. At the same time, I may point out, the view which I put forward at a recent meeting of the Society, *viz.*, that a considerable transfer of air takes place in the day-time from the land to the sea, also receives confirmation; and, regarded as a whole, the resulting phenomenon is, to my mind, a very beautiful and at the same time simple solution of a problem in meteorological physics.

The data which have given occasion to this communication have reached me only within the last few weeks. They are the reduced logs, relating to Indian seas, for the month of January, which have been accumulated for many years past by the London Meteorological Office, established by the late Admiral Fitzroy, and now under the direction of Mr. R. H. Scott and Captain H. Toynbee. The observations have all been made with compared instruments and have been corrected to the Kew standard; and the extracted observations have been carefully sifted in the course of extraction, and all doubtful entries rejected. Those which I shall now discuss are the barometric readings of ships north of latitude 20°, approaching and leaving the Sandheads; and are therefore all taken between distances of 60 and 120 miles from the coast. The observations having been made with marine mercurial barometers, it is probable that the amplitude of the range shewn by them may be somewhat less than would be shewn by barometers with large tubes, were it practicable to use such instruments on board ship; but all the instruments issued by the Marine Meteorological Department (and such only have been employed) have been subjected to a preliminary testing for sensitiveness and those only selected which have satisfied the test. It is therefore improbable that any large correction would be required to render the present data strictly comparable with those of a standard barometer.

The theory of diurnal land- and sea-breezes, as I understand it, is as follows. Under the morning sun, the air resting on a land-surface is more expanded than that resting on the sea; the larger part of the absorbed solar heat being used up, in the former case, in heating the air, while in the latter it is chiefly employed in evaporating water and charging the air with vapour; and, as I shewed in a former paper, the pressure of a given volume of air, when heated, is raised more than seven times as much as when the same amount of heat is consumed in charging it with vapour. The exact proportion at a temperature of 80° is 7·27. The expansion that follows in the two cases is not, however, quite in the same proportion, because more heat is consumed in work in the one case than in the other. Supposing that the expansion takes place under the same pressure in both cases, the ratios of expansion, for the same absorption of heat, would be 5·44 times as great in the case of the heated air as in that of the air charged with vapour, at the assumed temperature. The chief effect of this unequal expansion is to tilt the planes of equal pressure *(de, fg)* somewhat as represented in the accompanying diagram, and to produce a *head of pressure* at a certain height in the atmosphere over the land; while at the land- and sea-surface the pressure is perhaps but little altered.

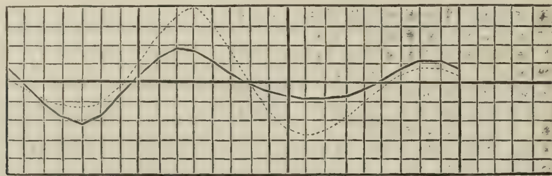


This process goes on as long as the temperature is rising; and the result is a current of air, at a certain height in the atmosphere, blowing from the land to the sea. But this transfer of air from the land- to the sea-atmosphere, while tending to restore equilibrium at the higher level, produces an increase of static pressure at the sea-surface, and reduces that at the land-surface; and therefore, a return current sets in at the lower level, which is the well known sea-breeze. As is well known, the sea-breeze sets in first on the coast-line; and as the day advances it extends in both directions, coming from further out at sea and penetrating to a greater distance inland. This continues till the equilibrium at the ground-surface is restored, which, however, does not occur until late in the evening. At Calcutta, the anemometer trace shews that, on an average, the retardation of the sea-breeze is such that it does not set in fairly until about 5 or 6 in the afternoon. Its prevalence, for some hours after this, is familiar to all residents in Calcutta in the cool southerly wind which, in the hot weather, sets in about the hour of the evening drive, is at its height about the usual dinner-hour, and makes the south verandah so pleasant for the post-prandial lounge. It lulls gradually, and as a rule ceases to be felt about midnight. Meanwhile, the cooling of the lower and more heated strata of the air, by reducing their elasticity, allows the higher strata to sink under the influence of gravity; and this, the more rapidly, the faster the cooling proceeds; and since, in virtue of the momentum acquired during the interval of more rapid cooling, the motion continues, after the contraction has begun to relax, the lower strata are dynamically compressed, producing the evening maximum of barometric pressure. As the expansion in the morning is greatest over the land, so also is the contraction in the evening; and, owing to this, the isobaric planes at a certain elevation are again disturbed, sinking lower over the land and producing a head of pressure over the sea. This disturbance causes a transfer of air from over the sea to the land at the higher level; and is followed by an accumulation of pressure at the land-surface, causing the outflow of the land-wind in the early morning hours.

According to this theory, then, there should be an excess of pressure over the land in the morning and as long as the land-wind prevails, and an excess of pressure over the sea in the afternoon and evening; and we might expect that, at the time of the afternoon minimum, when, according to the theory of the barometric tides, the air is exercising simply a static pressure, the minimum of the sea-curve would shew a much less depression than the land-curve, while the reverse would hold good at the time of the morning minimum. A comparison of the Calcutta curve with that of the head of the Bay, superimposed in the accompanying diagram, shews that these relations really obtain in nature. Any small increase in the amplitude of the marine barometric curve which may be required to render it strictly comparable with that of the Calcutta standard barometer, would only have the effect of increasing the difference of the night maximum and minimum, and somewhat diminishing that of the morning maximum and afternoon minimum.

In the diagram, I have represented the curves as deviations from the same line of mean pressure. Actually, in January, the mean pressure of the land is in general lower than that over the sea. It must be remembered also that the places represented are 80 or 90 miles from the coast-line; and therefore quite on the limits of the belt within which the daily oscillation of the surface-winds is experienced. I anticipate that, when the data for March and April shall be brought into comparison in like manner, the two curves will shew a still greater difference, indicating a greater transfer of air.

The following are the values for the six hours of observation, deduced from the marine registers; the co-efficients of Bessel's formula, computed therefrom; and the hourly values calculated from the formula: in conjunction with which I give also the corresponding values for the Calcutta curve.



Means of observations of Pressure. Sandheads. January.

Hour.	No. of obs.	Mean.	Hour.	No. of obs.	Mean.	Hour.	No. of obs.	Mean.
Mid.	37	30·029	8	46	30·047	16	38	30·004
4	62	29·983	Noon.	64	30·042	20	50	30·027

Bessel's formula. Sandheads. January.

$$x = 30{\cdot}022 + {\cdot}0068 \sin (n\ 15^\circ + 272^\circ\ 27') + {\cdot}0288 \sin (n\ 30^\circ + 152^\circ\ 3') + {\cdot}0093 \sin (n\ 45^\circ + 90^\circ).$$

Computed values. Sandheads and Calcutta. January.

Hour.	Sandheads.	Calcutta.	Hour.	Sandheads.	Calcutta.
Mean	30·022	30.011	Mean.	30·022	30·011
Mid.	+ ·016	+ ·003	Noon.	+ ·011	+ ·032
1	— ·001	— ·006	13	— ·001	— ·002
2	— ·021	— ·015	14	— ·010	— ·031
3	— ·037	— ·021	15	— ·014	— ·048
4	— ·042	— ·024	16	— ·016	— ·054
5	— ·033	— ·020	17	— ·016	— ·051
6	— ·013	— ·005	18	— ·014	— ·040
7	+ ·010	+ ·021	19	— ·008	— ·024
8	+ ·028	+ ·050	20	+ ·002	— ·007
9	+ ·037	+ ·072	21	+ ·014	+ ·006
10	+ ·035	+ ·078	22	+ ·023	+ ·012
11	+ ·024	+ ·062	23	+ ·024	+ ·010